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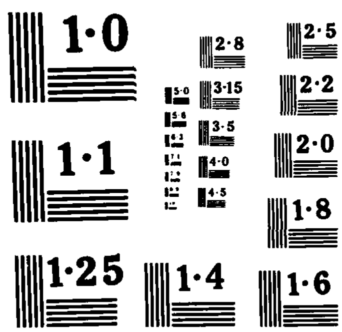
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THESIS

MULTIPLE SENSOR TRACKING IN THE
INTERIM BATTLE GROUP TACTICAL TRAINER

by

Keith N. Spangenberg

March 1985

Thesis Advisor: Rex H. Shudde

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The thesis provides two subroutines for the Interim Battle Group Tactical Trainer (IBGTT). The first subroutine is a single sensor tracking model using the Kalman filter. This subroutine is part of the Passive Sonar Model. The second subroutine is a multiple sensor tracking model using the Kalman filter to correlate all sensor contacts on a specific target. This subroutine is a separate entity and can be turned

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Multiple Sensor Tracking in the Interim Battle Group Tactical Trainer

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEM TECHNOLOGY
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ABSTRACT

The thesis provides two subroutines for the Interim Battle Group Tactical Trainer (IBGTT). The first subroutine is a single sensor tracking model using the Kalman filter. This subroutine is part of the Passive Sonar Model. The second subroutine is a multiple sensor tracking model using the Kalman filter to correlate all sonar contacts on a specific target. This subroutine is a separate entity and can be turned on or off at simulation initiation as required by training objectives.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

The Naval Ocean Systems Center has developed the Interim Battle Group Tactical Trainer/Computer Support Facility (IBGTT/CSF) as a computer-based tactical simulation system to provide a training device for senior naval officers to practice tactical decision making until such time as the Enhanced Naval Warfare Gaming System becomes available. The trainer is intended to provide interactive, multithreat, multiplatform operational situations in a simulated yet realistic operational environment so that selected officers can study, practice, and be evaluated in force-level tactical decision making.

The IBGTT training capability is implemented as a real-time, man-interactive, computer-aided (discrete event, time step) simulation of the naval warfare environment. In operation, the IBGTT supports a two-sided (BLUE vs. ORANGE) interactive scenario in which opposing sides can define, structure, and dynamically control forces ranging in size from one or more battle groups and associated aircraft, down to a single air or surface unit. Force elements and their associated characteristics, sensors, weapons, and communication systems may be derived from real, proposed, or conceptualized units or systems.

The utilization of IBGTT involves the use of the four major Naval Warfare Interactive Simulation System (NWISS) processes; BUILD, FORCE, WARGAME, and POST-GAME ANALYSIS. The BUILD process is a stand alone interactive program used to create and maintain platform, sensor, communication, and weapon characteristics in the IBGTT Characteristic Data Base. The FORCE process is a stand alone interactive program used to create and maintain an exercise scenario using the

data base created by the BUILD process. The WARGAME process is an interactive program used to accept and execute user orders; control platform motion, detections, and communications; determine engagement and other event outcomes; and display status information and tactical situations. The POST-GAME ANALYSIS process analyzes and lists critical data recorded during the exercise; supports exercise reconstruction; and tentatively evaluates some Measures of Effectiveness.

A global data area in NWISS, called the blackboard, is shared by all the major modules functioning during the exercise. It is the area where these modules interface with each other through the application of uniform naming conventions and the efficient use of memory. The blackboard is essentially comprised of numerous tables and subtables. Each table is assigned specific pointers while each subtable is assigned specific indices. The tables and subtables contain the fields (data) that are unique to that particular table or subtable. Each data item in the blackboard is referred to as a field and includes both whole words and specific bits. The field names are structured to provide the identity of the associated pointers and indices as well as the data type in the field.

Effective training at this level requires models of naval warfare interactions which provide realistic results based on an emulation of the actual warfare system. NWISS uses a wide variety of models to simulate the behavior of platforms, weapons, sensors, and communication systems. However, many of these models do not emulate the actual warfare system nor do they provide realistic results. Therefore, it is necessary to improve or replace these deficient models in order to obtain effective training and meet the objectives for which IBGTT was designed.

This thesis will address two models in particular. The first model is the Target Motion Analysis (TMA) Model which processes passive sonar contacts. The current model will be examined, followed by a presentation of a Kalman filter improvement to the model. Secondly, the Sonar Correlation Model will be examined, followed by a presentation of a Kalman filter to replace the current model.

The reader should be advised that the TMA Kalman Filter Model is in actuality equivalent to the Sonar Correlation Kalman Filter Model, as will become evident in the presentation of the two Kalman Filter Models. This thesis further presupposes that the reader is familiar with the Kalman filter.

II. SINGLE SENSOR TRACKING

A. TARGET MOTION ANALYSIS (TMA) MODEL

The current model will monitor the number of game minutes for which passive contact has been held on each target by each detecting passive sonar (i.e., submarine, surface sonar, towed array, or sonobuoy). When this time exceeds the TMA time defined by the user at simulation initiation a target motion analysis report will be displayed on the Passive Sonar Status Board. The TMA range, course, and speed displayed are derived as follows:

$$\text{TMA}\begin{bmatrix}\text{range}\\ \text{course}\\ \text{speed}\end{bmatrix} = \text{Actual target}\begin{bmatrix}\text{range}\\ \text{course}\\ \text{speed}\end{bmatrix} \pm \text{FACTOR}$$

The FACTOR is the product of a random number drawn from a uniform distribution and a derived parameter.

These parameters, which are indicated in Table I, cause increasingly accurate solutions to be developed as Signal Excess (SE) increases and as the target's true bearing changes (•B=delta B) from the true bearing of its initial detection. This latter factor simulates improved solutions derived from higher bearing rate targets and longer tracking times. The solution quality displayed will be selected from Table II as a function of SE and •B.

Once a TMA solution has been displayed, only the range is updated on the display. The range only update continues until the signal excess and/or change in true bearing cause a new parameter to be developed from the table (e.g., SE changes from -6 to -5 or •B changes from 5 to 6). When a new parameter is selected, a new TMA range, course, and quality

APPENDIX A

SINGLE SENSOR MODEL (RATIONAL FORTRAN)

```
Subroutine LCLTMA(LCL$Pointer,        #LCL Table Pointer
                  RORLAT,             #LAT of BRG-line ORIGIN
                  RORLON,             #LON of BRG-line ORIGIN
                  LBEAR,              #integer SONAR TGT BRG
                                      #     with Heading error
                  I_ICL$PMATRIX,      #Kalman P matrix
                  I_LCL$LASTTMATIME)  #Game minute of last fix update
##########################################################################
#
# Purpose:LCLTMA determines TMA solutions for a detector,using a Kalman
#         filter, and stores data (for the Passive Sonar ASTAB) in the
#         LCL Table.
#
# Called by: LCLPSN
#
# Calls: MUL4X4  RRB2LL
#
##########################################################################

BBcommon
```

IV. TEST RESULTS

The single sensor and multiple sensor models have been tested on a limited basis. Each subroutine has been tested independently to insure that the models perform as designed. However, the subroutines have not been tested for integration into the overall NWISS program or other subroutines.

Due to time constraints and computer availability, integration tests were not possible. The added blackboard space required has not been made but should not pose any problems. Inherent with any new subroutine is the unforeseeable affect it may have on unrelated subroutines. This aspect of testing has not been performed.

The track quality will be the same as that presented in Chapter Two.

D. CHANGES TO OTHER SUBROUTINES

The rational FORTRAN and source code listing for this model are contained in Appendix C and D, respectively. The changes presented in Chapter Two for Subroutine WARCYC are also applicable to this model. The only other change that will be necessary is that all active information needs to be added to the Remote Table.

no fix or track is associated with the correlation. As a result, each game minute two bearing lines are displayed (they may not be the same two from the previous minute nor necessarily an improvement) that jump around the screen, providing no useful information to the user.

The Kalman Filter Model permits all the information available, both active and passive, to be correlated on a specific target and be displayed as a fix with an updated track. In addition, the track quality associated with the fix provides the user with the added information about the relative size of the AOP. The on and off ability of the Sonar Correlation Model will be incorporated into the Kalman Filter Model for the previously stated reasons concerning its flexibility.

C. KALMAN FILTER MODEL

As mentioned in the introduction, the single sensor tracking model is in actuality equivalent to the multiple sensor tracking model. The difference being the scope of the information being processed. The single sensor model is a subset of the Passive Sonar Model; whereas, the Multiple sensor model is a separate entity correlating all available information. The basics of the models, including assumptions and initial conditions, are the same. Therefore, only the differences from the single sensor tracking model, presented in Chapter Two, will be discussed here.

The model will handle bearing and range measurements as well as bearing only measurements. The bearings are ±.5 degrees and the ranges are ±.5 nautical miles. For the bearing only measurement, the H matrix will be the same as for the single sensor tracking model. For the bearing and range measurement, the following H matrix will be utilized:

$$H = \begin{bmatrix} -\sin(\text{theta})/\text{range} & \cos(\text{theta})/\text{range} & 0 & 0 \\ \cos(\text{theta}) & \sin(\text{theta}) & 0 & 0 \end{bmatrix}$$

III. MULTIPLE SENSOR TRACKING

A. SONAR CORRELATION MODEL

The Sonar Correlation Model would be more appropriately described as a procedure instead of a model. This routine determines the correlation of bearings between two detecting units at a specific target and performs two functions. First, the two detecting units (with an intersection angle of at least 60 degrees, or else the largest available angle) to a common target will display bearing lines. Second, multiple targets detected within a certain maximum arc will display only one line; and will set the composition field set (i.e., one, few, or many). All other passive sonar lines will not be displayed.

The Sonar Correlation Model can be turned on or off. This allows for the flexibility of being utilized for Battle Group Commanders and their staff when the "big picture" is the main concern and not the individual unit prosecution; and yet, be turned off when the trainer is being utilized for a single unit or group of units practicing coordinated operations.

B. KALMAN FILTER REPLACEMENT

The current procedure has many drawbacks. Only passive sonar lines are considered; active information is displayed separately and is not correlated with the passive information.

The routine searches through the Remote Table until it finds two bearing lines that meet the 60 degree criteria. These are displayed and the routine ceases to search; thus, not necessarily choosing the optimum solution. In addition,

2. <u>Subroutine LCLPSN</u>

- Change line 9 to read:

```
EQUIVALENCE (IBB,FBB,CBB,IBBW,IBBB,PBB)
```

This includes the blackboard of the P matrix.

- After line 113 add:

```
I_LCL$LASTTMATIME=(IAND(ISHFT(IBB(KPOINT_LCL
*+1),-0),65535)
```

This time is used in Subroutine LCLTMA.

- Change line 262 to read:

```
IF(.NOT.(I_LCL$OMNIFLAG.NE.1))GOTO 23269
```

This removes the TMA exceed time criteria.

- Change line 264 to read:

```
LCLTMA(KPOINT_LCL,RORLAT,RORLON,LBEAR,
*I_LCL$PMATRIX,I_LCL$IASTTMATIME)
```

- If the 2-sigma axis is less than or equal to 500 yards, then the track receives a quality of GOOD. The criteria of 500 yards is used because the Engagement Model employs a 500 yard kill radius for a torpedo.
- If the 2-sigma axis is greater than 500 yards but less than or equal to 1000 yards, then the track receives a quality of FAIR. The criteria of 1000 yards was chosen simply because it is twice the GOOD criteria.
- If the 2-sigma axis is greater than 1000 yards, then the track receives a quality of POOR.

E. CHANGES TO OTHER SUBROUTINES

Implementation of this subroutine (LCLTMA, rational FORTRAN and source code listing are contained in Appendix A and B, respectively) will require some changes to other subroutines and additions to the blackboard. These changes and/or additions include:

1. Subroutine WARCYC

Each target needs a P(0) matrix in the blackboard; therefore, add:

```
      REAL PBB(4,4)
      REAL I_LCL$PMATRIX(4,4),I_RMT$PMATRIX(4,4)
      DO 50000 J=1,4
      DO 50001 K=1,4
      IF(.NOT.(J.EQ.K))GOTO 50001
      PBB(J,K) = 1000.
      GOTO 50000
50001 PBB(J,K) = 0.
50000 CONTINUE
      I_LCL$PMATRIX = PBB
      I_RMT$PMATRIX = PBB
```

θ_0 is the initial observation

and

$$P(0) = \begin{bmatrix} 1000 & 0 & 0 & 0 \\ 0 & 1000 & 0 & 0 \\ 0 & 0 & 1000 & 0 \\ 0 & 0 & 0 & 1000 \end{bmatrix}$$

Note: 1000 was chosen since it is approximately equal to ± one convergence zone (32 nm) and ± 32 knots.

The first assumption is that

E[W(k)*V(j)$transpose] = 0 for all j and k.

This means that the plant noise and the measurement noise are uncorrelated. Secondly, recall that the assumption is that during an encounter, the target's course and speed remain constant.

D. TRACK QUALITY

In order to reduce the number of changes required to the overall program, the TMA quality currently used from Table II will be utilized but based on different criteria. This will eliminate the need to change the blackboard; and more importantly, will not change the Status Tableau seen by the player, which is already full.

The track quality is based on the semi-major axis of the AOP. This is determined from the error covariance matrix as follows:

$$(\text{semi-major axis})^2 = (p11+p22)/2+\text{SQRT}[(p11-p22)^2/4+p12^2]$$

where pij are the elements of the P(t) matrix. A 2-sigma semi-major axis is used to insure a probability of 0.8647. The track quality is then determined as follows:

V(t) is the measurement noise. It is approximately N(0,R(t)). For this model, all bearings are ± .5 degrees.

K(t) is the Kalman gain. The update from X$hat(t) just before the measurement to X$hat(t) just after the measurement is proportional to the shock; the Kalman gain is the proportionality constant.

It was stated earlier that the measurements are assumed to be linearly related to the system state. Since the measurement is in polar coordinates, h(x) is in fact nonlinear. Therefore, a transformation must be made on h(x) to give a linearly related H.

In this model, the observation will be made from a platform at (u,w) to a target at (x,y), where x is north and y is east. So,

h(X) = theta = $\tan^{-1}$[(y-w)/(x-u)]

or,

H = [∂h(X)/∂x ∂h(X)/∂y ∂h(X)/∂x' ∂h(X)/∂y']
∂ represents the partial derivative

evaluated at X = X$hat. Hence,

H = [-sin(theta)/range cos(theta)/range 0 0]

This model was built upon two initial conditions and two important assumptions. The initial conditions are:

E[X(0)] = X$hat(0)

and

E[{X(0)-X$hat(0)}*{X(0)-X$hat(0)}$transpose]= P(0)

where

X$hat(0) = [32cos$\theta_0$ 32sinθ_0 0 0]$transpose

P is the error covar: ce matrix.

```
P(t) = E[ {X(t)-X$h  (t)}*{X(t)-X$hat(t)}$transpose ]
```

W(t) is the plant noise. It describes the randomness of the system as it moves from state X(t) to X(t+1). W(t) is approximately N(0,Q(t)). For this model, Q is taken to be zero.

Next, a new fix is computed based on an observation. This is determined from the measurement model:

```
Z(t) = H(t)*X(t) + V(t)
```

Thus, mea. irement is:

Kalman Gain: K(t)=

```
P(t)*H$transpose(t)*[H(t)*P(t)*H$transpose(t)
     + R(t)]^-1,
```

State Update:

```
X$hat(t) := X$hat(t) + K(t)*[ Z(t)-H(t)*X$hat(t) ],
```

and

Error Covariance Update:

```
P(t):=P(t)-K(t)*[ P(t)*H$transpose(t) ]$transpose
```

where

:= indicates that the right hand side is computed and replaces the value on the left hand side of the symbol.

Z(t) is the actual measurement. The measurements are assumed to be linearly related to the system state X(t) by the observation matrix H(t). Note: H(t)*X$hat(t) is the predicted outcome of the measurement. The difference, Z(t)-H(t)*X$hat(t), is the measurement residual or shock.

problem since the computed AOF updates smoothly with the sensor information.

C. KALMAN FILTER MODEL

First of all, it is assumed that during an encounter, the target's course and speed remain constant. The model updates the position of the fix since the last observation based on the previous estimate. This is based on the system model:

X(t) = PHI(t-1)*X(t-1)+W(t-1)

Thus, movement is:

State Extrapolation: X$hat(t) = PHI(t-1)*X$hat(t-1)

and

Error Covariance Extrapolation:
P(t) = PHI(t-1)*P(t-1)*PHI$transpose(t-1) + Q(t-1)

where

X$hat is the estimated state vector. It is assumed to be multivariate normal with mean zero.

X(t) = [x(t) y(t) x' y']$transpose
x'= x velocity
y'= y velocity

PHI is the transition matrix. It describes how the state vector changes from X(t) to X(t+1).

$$PHI = \begin{bmatrix} 1 & 0 & \bullet t & 0 \\ 0 & 1 & 0 & \bullet t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \bullet t = \text{delta } t$$

B. KALMAN FILTER IMPROVEMENTS

The model does not begin to compute a track until the TMA time defined by the user at simulation initiation is exceeded. This implies that all sensors and operators are equal, which is not realistic. Furthermore, this does not allow for accurate information to be used at time of detection unless the TMA time has already been exceeded. For instance, a passive sonobuoy dropped in front of a contact, producing a CPA (closest point of approach) for its initial detection, would have good track information that would not be utilized by the model; for only information after the TMA time is used in determining the FACTOR.

This TMA initiation time was included in the model because use of actual target information provided too accurate of a fix, even with bad sensor information, for a player to experience a realistic prosecution. The Kalman Filter Model eliminates the need for this waiting time since the model receives information as an operator would see it (that is, appparent bearing resulting from apparent position, including navigation error, and sensor bearing error). Thus, the Kalman Filter Model allows use of all sensor information with appropriate errors to provide realistic prosecution.

The TMA model attempts to simulate a changing area of probability (AOP) with improved solutions taken from the table as SE increases and true bearing changes. The problem of using true information instead of apparent has already been discussed. In addition, the improved AOP is heavily dependent upon the drawing of a random number. It has been observed in actual trainers that the AOP fluctuates as randomly as the random number generator, regardless of sensor information; providing confusing information to the player. Again, the Kalman Filter Model eliminates this

0 < SE	.2S	.1S	.05S	0

R = Actual Range
S = Actual Speed

TABLE II

TMA Quality

SIGNAL EXCESS (SE) IN dB / BEARING CHANGE IN DEGREES (•B)	•B<5	5<•B≤15	15<•B≤45	45<•B
SE ≤ -12	POOR	POOR	FAIR	FAIR
-12 ≤ SE ≤ -6	POOR	FAIR	FAIR	FAIR
-6 ≤ SE ≤ 0	FAIR	FAIR	FAIR	GOOD
0 < SE	FAIR	FAIR	GOOD	GOOD

will be calculated and displayed. Between TMA changes, the displayed range is updated each simulation cycle to show the range of the target estimated from the TMA course and speed.

If contact is lost for a time greater than the user-defined track loss time, the TMA solution will no longer be displayed. At any subsequent redetection of the same target, a new solution will be generated after the appropriate time interval has passed.

TABLE I

TMA Error Parameters

RELATIVE RANGE ERROR

SIGNAL EXCESS (SE) IN dB / BEARING CHANGE IN DEGREES (•B)	•B≤5	5<•B≤15	15<•B≤45	45<•B
SE ≤ -12	R	.8R	.7R	.4R
-12 < SE ≤ -6	.8R	.7R	.4R	.25R
-6 < SE ≤ 0	.7R	.4R	.25R	.1R
0 < SE	.4R	.2R	.1R	.05R

COURSE ERROR IN DEGREES

SIGNAL EXCESS (SE) IN dB / BEARING CHANGE IN DEGREES (•B)	•B≤5	5<•B≤15	15<•B≤45	45<•B
SE ≤ -12	120	90	45	30
-12 < SE ≤ -6	90	45	30	15
-6 < SE ≤ 0	45	30	15	7
0 < SE	30	15	7	5

RELATIVE SPEED ERROR

SIGNAL EXCESS (SE) IN dB / BEARING CHANGE IN DEGREES (•B)	•B≤5	5<•B≤15	15<•B≤45	45<•B
SE ≤ -12	.5S	.4S	.3S	.2S
-12 < SE ≤ -6	.4S	.3S	.2S	.1S
-6 ≤ SE ≤ 0	.3S	.2S	.1S	.05S

```
real  XEST(4),X(4)                   #System Model State Vector
      PHI(4,4)                       #System Model Transition Matrix
      PHIT(4,4)                      #Transpose of Transition Matrix
      P(4,4),I_LCL$PMATRIX(4,4)      #Error Covarianc     rix
      H(4)                           #Measurement Model Observation Matrix
      K(4)                           #Kalman Gain
      Z                              #Measurement Vector

lcl$TMALAT$F=xlcl$TMALAT$F           #Estimated LAT/LON
lcl$TMALON$F=xlcl$TMALON$F           #                   of TGT
lcl$TMACSE$F=xlcl$TMACSE$F           #Estimated COURSE and
lcl$TMASPD$F=xlcl$TMASPD$F           #         SPEED of TGT

#MOVEMENT:
                                     #State Extrapolation:
      XEST(1)=X                      #Distance in north-south direction
      ANGPI(DELLON)                  #Insure shortway around earth
      XEST(2)=Y                      #Distance in east-west direction
      XEST(3)=X$dot                  #Speed vector in north-south direction
      XEST(4)=Y$dot                  #Speed vector in east-west direction

    #Initialize PHI Matrix
      PHI(1,3)=PHI(2,4)=$delta$time    #Movement time in hrs since last
```

```
                                   #update

    #X$hat=PHI*X$hat             #State Extrapolation Vector

    #PHI$transpose
    #P=PHI*P*PHI$transpose       #Error Covariance Extrapolation

#MEASUREMENT:

    #Estimated bearing
    #Estimated range

                                 #Measurement Observation Matrix
     H(1)=-SIN(THETA$hat)/RNG$hat      #H$transpose=H
     H(2)=COS(THETA$hat)/RNG$hat
     H(3)=H(4)=0.

    #P*H$transpose               =(P*H$transpose)$transpose
    #H*P*H$transpose
    #H*P*H$transpose+R           R=BRG measurement error=±.5 degrees
    #Kalman Gain
    #H*X$hat
     ZHX=Z-HX                    #Measurement Residual
    #K*(Z-H*X$hat)
```

```
    #X$hat=X$hat+K*(Z-H*X$hat)     State Update

    #K*(P*H$transpose)$transpose
    #P=P-K*(P*H$transpose)$transpose   #Error Covariance Update

#New estimated bearing
#New estimated range

#Compute LAT/LON of BRG/RNG from ORIGIN
     CALL RRB2LL(_                  #Get LAT/LON
               F_LCL$TMALAT,   #ORIGIN LAT -> FIX LAT (input/output)
               F_LCL$TMALON,   #ORIGIN LON -> FIX LON (input/output)
               RNG,            #Range from ORIGIN to TGT
               THETA,          #Bearing from ORIGIN to TGT
               0.0,            #Pass zero
               COSL)           #Cosine of LAT (input/output)

putLCL$TMALAT$f             #New FIX position
putLCL$TMALON$f

#New estimated course
#New estimated speed
```

```
putLCL$TMACSE$f              #New FIX course
putLCL$TMASPD$f              #    and speed

#Determine semi-major axis of area of probability
    #SIGMA$squared=(P11+P22)/2+SQRT{((P11-P22)+(P11-P22))/4+P12*P12}
    #2SIGMA=2*SIGMA/2025 yds

if(2SIGMA <= 500 yds)then
   TMA$Quality=2             #GCOD
else if(2SIGMA > 500 yds & <= 1000 yds)then
   TMA$Quality=1             #FAIR
else(2SIGMA > 1000 yds)
   TMA$Quality=0             #PCOR

return
end          #End lclTMA
##############################################################################
Subroutine MUL4X4(A,         #4X4 matrix (input)
                  B,         #4X4 matrix (input)
                  C)         #4X4 matrix (output)
##############################################################################
#
```

```
# Purpose: Multiplies two 4X4 matrices together.                        LCL01140
#                                                                       LCL01150
# Called by: LCLTMA  CORSNR                                             LCL01160
#                                                                       LCL01170
########################################################################LCL01180
                                                                        LCL01190
C=A*B                                                                   LCL01200
                                                                        LCL01210
return                                                                  LCL01220
end             #End MUL4X4                                             LCL01230
```

APPENDIX B

SINGLE SENSOR MODEL (SOURCE CODE)

```
      SUBROUTINE LCLTMA(KPOINT_LCL,RORLAT,RORLON,LBEAR,I_LCL$PMATRIX,I_L
     *CL$LASTTMATIME)
      IMPLICIT REAL*8 (A,C)
      INTEGER IBB(1025),IBBP(6,85)
      INTEGER*2 IBBW(2,1025)
      BYTE IBBB(4,1025)
      REAL*8 CBB(512)
      REAL FBB(1025),I_LCL$PMATRIX(4,4),P(4,4),KPHTT(4,4),H(4),PHT(4)
      REAL K(4),HPHT,HPHTR,HX,PROD(4),XEST(4),X(4),PHI(4,4),PHIT(4,4)
      REAL PBB(4,1025)
      EQUIVALENCE (IBB,FBB,CBB,IBBW,IBBB,PBB)
      EQUIVALENCE (IBB(513),IBBP)
      COMMON/BBOARD/IBB
      F_LCL$TMALAT=(IAND(ISHFT(IBB(KPOINT_LCL+8),-0),65535)*1.*.0001-3.2
     *)
      F_LCL$TMALON=(IAND(ISHFT(IBB(KPOINT_LCL+8),-16),65535)*1.*.0001-3.
     *2)
      F_LCL$TMACSE=(IAND(ISHFT(IBB(KPOINT_LCL+5),-0),511))
      F_LCL$TMASPD=(IAND(ISHFT(IBB(KPOINT_LCL+4),-16),4095))
      XEST(1)=F_LCL$TMALAT-RORLAT
      DELLON=F_LCL$TMALON-RORLON
```

```
      ANGPI(DELLON)
      COST=COS(F_LCL$TMALAT)
      COSL=COS(RORLAT)
      XEST(2)=.5*(COSI+COST)*DELLON
      XEST(3)=F_LCL$TMASPD*COS(F_LCL$TMACSE)
      XEST(4)=F_LCL$TMASPD*SIN(F_LCL$TMACSE)
      DO 50002 J=1,4
      DO 50002 K=1,4
      IF(.NOT.(J.EQ.K))GOTO 50003
      PHI(J,K)=1.
      GOTO 50002
50003 PHI(J,K)=0.
50002 CONTINUE
      PHI(1,3)=(IBB(103)-I_LCL$IASTTMATIME)/60.
      PHI(2,4)=PHI(1,3)
      DO 50004 J=1,4
      X(J)=0.
      DO 50004 K=1,4
50004 X(J)=X(J)+PHI(J,K)*XEST(K)
      DO 50005 J=1,4
      DO 50005 K=1,4
50005 PHIT(J,K)=PHI(K,J)
      CALL MUL4X4(PHI,I_LCL$PMATRIX,P)
      CALL MUL4X4(P,PHIT,I_LCL$PMATRIX)
```

```
      THETA=FATAN2(X(2),X(1))
      THETA=INT(THETA*(180./3.141592654)+.5)
      RNG=SQRT(X(1)*X(1)+X(2)*X(2))
      H(1)=-SIN(THETA)/RNG
      H(2)=COS(THETA)/RNG
      H(3)=0.
      H(4)=0.
      DO 50006 J=1,4
      PHT(J)=0.
      DO 50006 K=1,4
50006 PHT(J)=PHT(J)+I_LCL$PMATRIX(J,K)*H(K)
      HPHT=0.
      DO 50007 J=1,4
50007 HPHT=HPHT+H(J)*PHT(J)
      HPHTR=HPHT+.25
      DO 50008 J=1,4
50008 K(J)=PHT(J)/HPHTR
      Z=FLOAT(LBEAR)
      HX=0.
      DO 50009 J=1,4
50009 HX=HX+H(J)*X(J)
      ZHX=Z-HX
```

```
      DO 50010 J=1,4                                                    LCL00680
50010 PROD(J)=K(J)*ZHX                                                  LCL00690
      DO 50011 J=1,4                                                    LCL00700
50011 XEST(J)=X(J)+PROD(J)                                              LCL00710
      DO 50012 J=1,4                                                    LCL00720
      DO 50012 L=1,4                                                    LCL00730
50012 KPHTT(J,L)=K(J)*PHT(L)                                            LCL00740
      DO 50013 J=1,4                                                    LCL00750
      DO 50013 K=1,4                                                    LCL00760
50013 I_LCL$PMATRIX(J,K)=I_LCL$PMATRIX(J,K)-KPHTT(J,K)                  LCL00770
      THETA=FATAN2(XEST(2),XEST(1))                                     LCL00780
      THETA=INT(THETA*(180./3.141592654)+.5)                            LCL00790
      RNG=SQRT(XEST(1)*XEST(1)+XEST(2)*XEST(2))                         LCL00800
      F_LCL$TMALAT=RORLAT                                               LCL00810
      F_LCL$TMALON=RORLON                                               LCL00820
      COSL=COS(F_LCL$TMALAT)                                            LCL00830
      CALL RRB2LL(F_LCL$TMALAT,F_LCL$TMALON,RNG,THETA,0.,COSL)          LCL00840
      IBB(KPOINT_LCL+8)=IOR(IAND(IBB(KPOINT_LCL+8),NOT(ISHFT(65535,0))),LCL00850
     *ISHFT(IAND(INT(.5+(F_LCL$TMALAT--3.2)/.0001),65535),0))           LCL00860
      IBB(KPOINT_LCL+8)=IOR(IAND(IBB(KPOINT_LCL+8),NOT(ISHFT(65535,16)))LCL00870
     *,ISHFT(IAND(INT(.5+(F_LCL$TMALON--3.2)/.0001),65535),16))         LCL00880
      CSE=FATAN2(XEST(4),XEST(3))                                       LCL00890
      CSE=INT(CSE*(180./3.141592654)+.5)                                LCL00900
      SPD=SQRT(XEST(3)*XEST(3)+XEST(4)*XEST(4))                         LCL00910
```

```
 IBB(KPOINT_LCL+5)=IOR(IAND(IBB(KPOINT_LCL+5),NOT(ISHFT(511,0))),IS
*HFT(IAND((CSE),511),0))
 IBB(KPOINT_LCL+4)=IOR(IAND(IBB(KPOINT_LCL+4),NOT(ISHFT(4095,16))),
*ISHFT(IAND((SPD),4095),16))
 CONST1=I_LCL$PMATRIX(1,1)-I_LCL$PMATRIX(2,2)
 CONST2=I_LCL$PMATRIX(1,2)*I_LCL$PMATRIX(1,2)
 CONST=SQRT(CONST1*CONST1/4.+CONST2)
 I_LCL$SIGMASQR=(I_LCL$PMATRIX(1,1)+I_LCL$PMATRIX(2,2))/2.+CONST
 I_LCL$2SIGMA=SQRT(I_LCL$SIGMASQR)*2./2025.
 IF(I_LCL$2SIGMA.LE.500)THEN
   I_LCL$TMAQUALITY=2
 ELSE IF(I_LCL$2SIGMA.GT.500.AND.I_LCL$2SIGMA.LE.1000)THEN
   I_LCL$TMAQUALITY=1
 ELSE
   I_LCL$TMAQUALITY=0
 END IF
 IBB(KPOINT_LCL+9)=IOR(IAND(IBB(KPOINT_LCL+9),NOT(ISHFT(3,4))),ISHF
*T(IAND((I_LCL$TMAQUALITY),3),4))
 FETURN
 END
 SUBROUTINE MUL4X4(A,B,C)
 DIMENSION A(4,4),B(4,4),C(4,4)
 DO 60000 I=1,4
 DO 60001 J=1,4
```

```
      S=0.                                                              LCL01160
      DO 60002 K=1,4                                                    LCL01170
60002 S=S+A(I,K)*B(K,J)                                                 LCL01180
60001 C(I,J)=S                                                          LCL01190
60000 CONTINUE                                                          LCL01200
      RETURN                                                            LCL01210
      END                                                               LCL01220
```

APPENDIX C

MULTIPLE SENSOR MODEL (RATIONAL FORTRAN)

```
Subroutine CORSNR
##########################################################################
#
# Purpose: (1) Correlate all sonar contacts (active and passive) and
#              store the updated FIX (Posit,CSE,SPD).
#          (2) Determine a TMA quality based on the criteria:
#              If the semi-major axis of the area of probability is:
#                (a) <= 500 yds
#                    TMA quality is GOOD
#                (b) > 500 yds & <= 1000 yds
#                    TMA quality is FAIR
#                (c) > 1000 yds
#                    TMA quality is POOR
#
# Called by: WARCYC
#
# Calls: CORR_SORT  MUL4X4  RRB2LL
#
##########################################################################
```

```
BBcommon
CORR$ccmmon

real XEST(4),X(4)                  #System Model State Vector
     PHI(4,4)                      #System Model Transition Matrix
     PHIT(4,4)                     #Transpose of Transition Matrix
     P(4,4),I_LCL$PMATRIX(4,4)     #Error Covariance Matrix
     H(4)                          #Measurement Model Observation Matrix
     KG(4),KGAIN(4,2)              #Kalman Gain
     Z(2)                          #Measurement Vector
     R(2,2)                        #Measurement Noise

                                   #Loop thru Remote Table
for(RMT$Pointer$First; RMT$Pointer$Valid; RMT$Pointer$Next)
   {
   if(xRMT$InUse$I==$no)next       #Finf the right slots
   RMT$DetectionType$i=xRMT$DetectionType$i
   if(RMT$DetectionType$i=$Sonar$Code)      #If sonar, set composition
     putRMT$Compositicn$I(1)                #    to 1
   }

if(Correlate$Sonar==$no)return
```

```
#_______________________________________________________________________
#Loop for each BLUE/ORANGE View

for(iview=$firstBLUE$view; iview<=$lastORANGE$view; iview=iview+1)
  {
  VUE$Pointer$To iview              #Get to the right view

  RMT$Pointer$To xVUE$FirstRmtIndx$i        #Set first and last
  istart=RMT$Pointer                        #    RMT Index as
  RMT$Pointer$To xVUE$LastRmtIndx$i         #    limits for loop
  iend=RMT$Pointer

  kore=0                            #Initialize counter
                                    #Loop for each RMT slot in View
  for(RMT$Pointer=istart; RMT$Pointer<=iend; RMT$Pointer$next)
    {
    if(XRMT$InUse$i==$no)next   #Skip if not in use
    RMT$DetectionType$i=xRMT$DetectionType$i   #Get Detection Type

    if(Correlate$Sonar==$yes & RMT$DetectionType$i==$Sonar$Code)
    *continue
    else next
```

```
      F_POS2$LAT=FBB(KPOINT_RMT)
      F_POS2$LON=FBB(KPOINT_RMT+1)
      F_POS2$COSLAT=FBB(KPOINT_RMT+13)
      X=F_POS2$LAT-F_POS1$LAT
      Y=F_POS2$LON-F_POS1$LON
      ANGPI(Y)
      COSL=COS(F_POS2$LAT)
      Y=.5*(F_POS2$COSLAT+F_POS1$COSLAT)*Y
      THETAK=FATAN2(Y,X)
      THETAK=INT(THETAK*(180./3.141592654)+.5)
      DK=SQRT(X*X+Y*Y)
      IBEAR(J1)=DK*SIN(IBEAR(J1)-THETAK)
70008 IF(.NOT.(I_RMT$DETECTIONTYPE.EQ.2))GOTO 70018
      H(1)=-SIN(THETA)/RNG
      H(2)=COS(THETA)/RNG
      H(3)=0.
      H(4)=0.
      DO 70019 JJ=1,4
      PHT(JJ)=0.
      DO 70019 KK=1,4
70019 PHT(JJ)=PHT(JJ)+I_RMT$PMATRIX(JJ,KK)*H(KK)
      HPHT=0.
```

```
      GOTO 70011                                                        COR00940
70012 PHI(JJ,KK)=0.                                                     COR00950
70011 CONTINUE                                                          COR00960
      F_RMT$DELTIME=(IBB(103)-IIAST(K1))/60.                            COR00970
      PHI(1,3)=F_RMT$DELTIME                                            COR00980
      PHI(2,4)=F_RMT$DELTIME                                            COR00990
      DO 70013 JJ=1,4                                                   COR01000
      X(JJ)=0.                                                          COR01010
      DO 70013 KK=1,4                                                   COR01020
70013 X(J)=X(J)+PHI(JJ,KK)*XEST(KK)                                     COR01030
      DO 70014 JJ=1,4                                                   COR01040
      DO 70014 KK=1,4                                                   COR01050
70014 PHIT(JJ,KK)=PHT(KK,JJ)                                            COR01060
      CALL MUL4X4(PHI,I_RMT$PMATRIX,P)                                  COR01070
      CALL MUL4X4(P,PHIT,I_RMT$EMATRIX)                                 COR01080
70015 IF(.NOT.(J.LE.KORE))GOTO 70016                                    COR01090
      J1=IPNT(J)                                                        COR01100
      IF(IDTEE(K1).NE.IDTEE(J1))GOTO 70017                              COR01110
      KPOINT_RMT=IRMTP(J1)                                              COR01120
      I_RMT$DETECTIONTYPE=(IAND(ISHFT(IBB(KPOINT_RMT+8),-29),3))        COR01130
      THETA=FATAN2(X(2),X(1))                                           COR01140
      THETA=INT(THETA*(180./3.141592654)+.5)                            COR01150
      RNG=SQRT(X(1)*X(1)+X(2)*X(2))                                     COR01160
      IF(K.EQ.J)GOTO 70008                                              COR01170
```

```
      J=K
70009 IF(.NOT.(K.LT.KORE))GOTO 70010
      K1=IPNT(K)
      KPOINT_RMT=IRMTP(K1)
      F_RMT$TMALAT=(IAND(ISHFT(IBB(KPOINT_RMT+8),-0),65535)*1.*.0001-3.2
     *)
      F_RMT$TMALON=(IAND(ISHFT(IBB(KPOINT_RMT+8),-16),65535)*1.*.0001-3.
     *2)
      F_RMT$TMACSE=(IAND(ISHFT(IBB(KPOINT_RMT+5),-0),511))
      F_RMT$TMASPD=(IAND(ISHFT(IBB(KPOINT_RMT+4),-16),4095))
      F_POS1$LAT=FBB(KPOIONT_RMT)
      F_POS1$LON=FBB(KPOINT_RMT+1)
      F_POS1$COSLAT=FBB(KPOINT_RMT+13)
      XEST(1)=F_RMT$TMALAT-F_POS1$LAT
      DELLON=F_RMT$TMALON-F_POS1$LON
      ANGPI(DELLON)
      COSL=COS(F_RMT$TMALAT)
      XEST(2)=.5*(COSL+F_POS1$CCSLAT)*DELLON
      XEST(3)=F_RMT$TMASPD*COS(F_RMT$TMACSE)
      XEST(4)=F_RMT$TMASPD*SIN(F_RMT$TMACSE)
      DO 70011 JJ=1,4
      DO 70011 KK=1,4
      IF(.NOT.(JJ.EQ.KK))GOTO 70012
      PHI(JJ,KK)=1.
```

```
*83))
      IEND=KPOINT_RMT
      KORE=0
      KPOINT_RMT=ISTART
70004 IF(.NOT.(KPOINT_RMT.LE.IEND))GOTO 70005
      IF(IBB(KPOINT_RMT+8).EQ.0)GOTO 70006
      I_RMT$DETECTIONTYPE=(IAND(ISHFT(IBB(KPOINT_RMT+8),-29),3))
      IF(IBB(256).EQ.1.AND.(I_RMT$DETECTIONTYPE.EQ.2.OR.I_RMT$DETECTIONT
*YPE.EQ.24))GOTO 70007
      GOTO 70006
70007 IF(KORE.GE.800)GOTO 70005
      KORE=KORE+1
      IRMTP(KORE)=KPOINT_RMT
      IDTOR(KORE)=(IAND(ISHFT(IBB(KPOINT_RMT+8),-10),1023))
      IDTEE(KORE)=(IAND(ISHFT(IEB(KPOINT_RMT+7),-0),1023))
      ILAST(KORE)=(IAND(ISHFT(IEB(KPOINT_RMT+2),-0),65535))
      IBEAR(KORE)=(IAND(ISHFT(IEB(KPOINT_RMT+7),-10),511))
      IRNGE(KORE)=(IAND(ISHFT(IEB(KPOINT-RMT+7),-0),511))
      IPNT(KORE)=KORE
70006 KPOINT_RMT=KPOINT_RMT+15
      GOTO 70004
70005 IF(KORE.EQ.0)GOTO 70099
      CALL CORR_SORT
      K=1
```

```
      IF (IBB(KPOINT_RMT+8).EQ.0)GOTO 70002                                    COR00220
      IBB(KPOINT_RMT+10)=IOR(IAND(IBB(KPOINT_RMT+10),NOT(ISHFT(1,29))),ICOR00230
     *SHFT(IAND((0),1),29))                                                    COR00240
      IBB(KPOINT_RMT+10)=IOR(IAND(IBB(KPOINT_RMT+10),NOT(ISHFT(1,28))),ICOR00250
     *SHFT(IAND(('00000001'X),1),28))                                          COR00260
      IBB(111)=1                                                               COR00270
      I_RMT$DETECTIONTYPE=(IAND(ISHFT(IBB(KPOINT_RMT+8),-29),3))               COR00280
      IF(.NOT.(I_RMT$DETECTIONTYPE.EQ.2.OR.I_RMT$DETECTIONTYPE.EQ.24))GOCOR00290
     *TO 70002                                                                 COR00300
      IBB(KPOINT_RMT+10)=IOR(IAND(IBB(KPOINT_RMT+10),NOT(ISHFT(3,23))),ICOR00310
     *SHFT(IAND((1),3),23))                                                    COR00320
      IBB(KPOINT_RMT+10)=IOR(IAND(IBB(KPOINT_RMT+10),NOT(ISHFT(1,28))),ICOR00330
     *SHFT(IAND(('00000001'X),1),28))                                          COR00340
      IBB(111)=1                                                               COR00350
70002 KPOINT_RMT=KPOINT_RMT+15                                                 COR00360
      GOTO 70000                                                               COR00370
70001 IF(IBB(256).EQ.0)GOTO 70099                                              COR00380
      IVIEW=IBB(129)                                                           COR00390
70003 IF(.NOT.(IVIEW.LE.IBB(132)))GOTO 70099                                   COR00400
      KPOINT_VUE=IBBP(1,06)-1540+1540*IVIEW                                    COR00410
      KPOINT_RMT=IBBP(1,56)-15+15*(IAND(ISHFT(IBB(KPOINT_VUE+1),-0),1638COR00420
     *3))                                                                      COR00430
      ISTART=KPOINT_RMT                                                        COR00440
      KPOINT_RMT=IBBP(1,56)-15+15*(IAND(ISHFT(IBB(KPOINT_VUE+1),-14),163COR00450
```

APPENDIX D

MULTIPLE SENSOR MODEL (SOURCE CODE)

```
      SUBROUTINE CORSNR
      IMPLICIT REAL*8 (A,C)
      INTEGER IBB(1025)
      INTEGER*2 IBBW(2,1025),IDTOR(800),IDTEE(800),ILAST(800),IBEAR(800)
      INTEGER*2 IRNGE(800),IPNT(800),KORE
      INTEGER*4 IRMTP(800)
      BYTE IBBB(4,1025)
      REAL*8 CBB(512)
      REAL FBB(1025),PBB(4,1025),H(4),PHT(4),KG(4),HPHT,HPHTR,HX,PROD(4)
      REAL KGAIN(4,2),I_RMT$PMATRIX(4,4),KPHTT(4,4),KKPHTT(4,4),R(2,2)
      REAL HH(2,4),HHT(4,2),PPHT(4,2),HHPHT(2,2),SUM(2,2),ADJ(2,2)
      REAL INVSUM(2,2),PHI(4,4),PHIT(4,4),P(4,4),HHX(2),PPHTT(2,4),X(4)
      REAL XEST(4),Z(2),KZHX(4)
      EQUIVALENCE (IBB,FBB,CBB,IBBW,IBBB,PBB)
      EQUIVALENCE (IBB(513),IBBP)
      COMMON/BBOARD/IBB
      COMMON/SCRPAD/IRMTP,IDTOR,IDTEE,ILAST,IBEAR,IRNGE,IPNT,KORE
      DATA R/.25,0.,0.,.25/
      KPOINT_RMT=IBBP(1,56)
70000 IF(.NOT.((KPOINT_RMT.GE.IBBP(1,56).AND.KPOINT_RMT.LT.(IBBP(1,56)+I
     *BBP(2,56)))))GOTO 70001
```

```
return
end            #End CORSNR
```

```
putRMT$TMALON$f

#New estimated course
#New estimated speed

putRMT$TMACSE$f              #New FIX course
putRMT$TMASPD$f              #    and speed

#Determine semi-major axis of area of probability
  #SIGMA$squared=(P11+P22)/2+SQRT{((P11-P22)+(P11-P22))/4+P12*P12}
  #2SIGMA=2*SIGMA/2025 yds

if(2SIGMA <= 500 yds)then
  TMA$Quality=2              #GOOD
else if(2SIGMA > 500 yds & <= 1000 yds)then
  TMA$Quality=1              #FAIR
else(2SIGMA > 1000 yds)
  TMA$Quality=0              #POOR

}k=j                         #Set pointer to next detectee

}
```

```
        #Z(2)=measured range
        #H*X$hat
        #Z-H*X$hat              Measurement Residual
        #K*(Z-H*X$hat)
        #X$hat=X$hat+K*(Z-H*X$hat)   State Update

        #(P*H$transpose)$transpose
        #K*(P*H$transpose)$transpose
        #P=P-K*(P*H$transpose)$transpose      Error Covariance Update
     }

#New estimated bearing
#New estimated range

#Compute LAT/LON of BRG/RNG from ORIGIN
   CALL RRB2LL(_           #Get LAT/LON
        F_RMT$TMALAT       #ORIGIN LAT->FIX LAT (input/output)
        F_RMT$TMALON       #ORIGIN LON->FIX LON (input/output)
        RNG                #Range from ORIGIN to TARGET
        THETA              #Bearing from ORIGIN to TARGET
        0.0                #Pass zero
        COSL               #Cosine of latitude (input/output)

putRMT$TMALAT$f            #New FIX position
```

```
  #K* (P*H$transpose)$transpose
  #P=P-K*(P*H$transpose)$transpose      Error Covariance Update

if(RMT$DetectionType != $Active$Sonar)break

  #irnge(j1)=observed range adjusted to ORIGIN platform

                               #Measurement Observation Matrix
  HH(2,1)=COS(THETA$hat)
  HH(2,2)=SIN(THETA$hat)
  HH(1,1)=-SIN(THETA$hat)/RNG$hat
  HH(1,2)=COS(THETA$hat)/RNG$hat
  HH(1,3)=HH(1,4)=HH(2,3)=HH(2,4)=0

  #H$transpose
  #P*H$transpose
  #H*P*H$transpose
  #H*P*H$transpose+R     R=BRG measurement error=±.5 degrees
                       # =RNG measurement error=±.5 naut. mi.
  #(H*P*H$transpose+R)$inverse
  #Kalman Gain

  #Z(1)=measured bearing
```

```
#THETAK=bearing from ORIGIN to DETECTOR
#DK=distance from ORIGIN to DETECTOR

ibear(j1)=DK*SIN(OBS BRG - BRG from ORIGIN)   #Observed bearing
                                              #adjusted to
                                              #ORIGIN platform

if(RMT$DetectionType != $Passive$Sonar) check for $Active$Sonar

                        #Measurement Observation Matrix
  H(1)=-SIN(THETA$hat)/RNG$hat     #H=H$transpose
  H(2)=COS(THETA$hat)/RNG$hat
  H(3)=H(4)=0

  #P*H$transpose          =(P*H$transpose)$transpose
  #H*P*H$transpose
  #H*P*H$transpose+R     R=BRG measurement error=±.5 degrees
  #Kalman Gain

  #Z(1)=measured bearing
  #H*X$hat
  #ZHX=Z(bearing)-H*X$hat     Measurement Residual
  #K*(Z-H*X$hat)
  #X$hat=X$hat+K*(Z-H*X$hat)  State Update
```

```
#MEASUREMENT:

      for(j=k; j<=kore; j=j+1)
         {
         j1=ipnt(j)

         if(idtee(k1) != idtee(j1))break

         KPOINT_RMT=irmtp(j1)      #Set pointer

         RMT$DetecticnType=xRMT$DetectionType    #Get Detection Type

         #Estimated bearing
         #Estimated range

         if(k=j)                    #ORIGIN platform
           POS2$LAT$F=xPOS2$LAT$F    #Get posit of next detector
           POS2$LON$F=xPOS2$LON$F
           POS2$COSLAT$F=xPOS2$COSLAT$F

         #Adjust contact bearing to ORIGIN
         #X=north-south distance from ORIGIN to DETECTOR
         #Y=east-west distance from ORIGIN to DETECTOR
```

```
    RMT$TMACSE$F=xRMT$TMACSE$F
    RMT$TMASPD$F=xRMT$TMASPD$F

    POS1$LAT$F=xPOS1$LAT$F      #Get posit of Detector
    POS1$LON$F=xPOS1$LON$F
    POS1$COSLAT$F=xPOS1$COSLAT$F

#MOVEMENT:
                         #State Extrapolation
    XEST(1)=X                   #Distance in north-south direction
    ANGPI(DELLON)               #Insure shortway around earth
    XEST(2)=Y                   #Distance in east-west direction
    XEST(3)=X$dot               #Speed vector in north-south direction
    XEST(4)=Y$dot               #Speed vector in east-west direction

    #Initialize the PHI matrix
      PHI(1,3)=PHI(2,4)=$delta$t    #Movement time in hrs since
                                    #    last update

    #X$hat=PHI*X$hat            State Extrapolation Vector

    #PHI$transpose
    #P=PHI*P*PHI$transpose      Error Covariance Extrapolation
```

```
        if(kore>=$Max$Corr)break          #Make sure that there are enough
                                          #    slots for the array
        kore=kore+1                       #Add to array counter
        irmtp(kore)=RMT$Pointer           #Save RMT Pointer
        idtor(kore)=xRMT$Detector$I       #Save Detector
        idtee(kore)=xRMT$Detectee$I       #Save Detectee
        ilast(kore)=xRMT$LastDetTime$I    #Save time of detection update
        ibear(kore)=xRMT$Bearing$I        #Save the bearing
        irnge(kore)=xRMT$Range$I          #Save the range
        ipnt(kore)=kore                   #Initialize sort index
        }

    if(kore==0)return                 #Quit if no tracks

    CALL CORR_SORT                    #Sort arrays by Detectee/Last-Det-Time

    for(k=1; k<kore; k=j)
        {
        k1=ipnt(k)

        KPCINT_RMT=irmtp(k1)          #Set pointer

        RMT$TMALAT$F=xRMT$TMALAT$F        #Get posit,CSE,SPD
        RMT$TMALON$F=xRMT$TMALON$F        #    of last TMA estimate
```

```
      DO 70020 JJ=1,4                                                   COR01400
70020 HPHT=HPHT+H(JJ)*PHT(JJ)                                           COR01410
      HPHTR=HPHT+.25                                                    COR01420
      DO 70021 JJ=1,4                                                   COR01430
70021 KG(JJ)=PHT(JJ)/HPHTR                                              COR01440
      Z(1)=FLOAT(IBEAR(J1))                                             COR01450
      HX=0.                                                             COR01460
      DO 70022 JJ=1,4                                                   COR01470
70022 HX=HX+H(JJ)*X(JJ)                                                 COR01480
      ZHX=Z(1)-HX                                                       COR01490
      DO 70023 JJ=1,4                                                   COR01500
70023 PROD(JJ)=KG(JJ)*ZHX                                               COR01510
      DO 70024 JJ=1,4                                                   COR01520
70024 X(JJ)=X(JJ)+PROD(JJ)                                              COR01530
      DO 70025 JJ=1,4                                                   COR01540
      DO 70025 KK=1,4                                                   COR01550
70025 KPHTT(JJ,KK)=KG(JJ)*PHT(KK)                                       COR01560
      DO 70026 JJ=1,4                                                   COR01570
      DO 70026 KK=1,4                                                   COR01580
70026 I_RMT$PMATRIX(JJ,KK)=I_RMT$PMATRIX(JJ,KK)-KPHTT(JJ,KK)            COR01590
      GOTO 70027                                                        COR01600
70018 IF(.NOT.(I_RMT$DETECTIONTYPE.EQ.24))GOTO 70027                    COR01610
      IF(K.EQ.J)GOTO 70028                                              COR01620
```

```
      IRNGE(J1)=SQRT(DK*DK+IRNGE(J1)*IRNGE(J1))                         COR01630
70028 HH(2,1)=COS(THETA)                                                COR01640
      HH(2,2)=SIN(THETA)                                                COR01650
      HH(1,1)=-H(2,2)/RNG                                               COR01660
      HH(1,2)=H(2,1)/RNG                                                COR01670
      HH(1,3)=0.                                                        COR01680
      HH(1,4)=0.                                                        COR01690
      HH(2,3)=0.                                                        COR01700
      HH(2,4)=0.                                                        COR01710
      DO 70029 JJ=1,4                                                   COR01720
      DO 70029 KK=1,4                                                   COR01730
70029 HHT(JJ,KK)=HH(KK,JJ)                                              COR01740
      DO 70030 JJ=1,4                                                   COR01750
      DO 70031 KK=1,2                                                   COR01760
      S=0.                                                              COR01770
      DO 70032 LL=1,4                                                   COR01780
70032 S=S+I_RMT$PMATRIX(JJ,LL)*HHT(LL,KK)                               COR01790
70031 PPHT(JJ,KK)=S                                                     COR01800
70030 CONTINUE                                                          COR01810
      DO 70033 JJ=1,2                                                   COR01820
      DO 70034 KK=1,2                                                   COR01830
      S=0.                                                              COR01840
```

```
      DO 70035 LL=1,4
70035 S=S+HH(JJ,LL)*PPHT(LL,KK)
70034 HHPHT(JJ,KK)=S
70033 CONTINUE
      DO 70036 JJ=1,2
      DO 70036 KK=1,2
70036 SUM(JJ,KK)=HHPHT(JJ,KK)+R(JJ,KK)
      DET=SUM(1,1)*SUM(2,2)-SUM(1,2)*SUM(2,1)
      ADJ(1,1)=SUM(2,2)
      ADJ(1,2)=-SUM(1,2)
      ADJ(2,1)=-SUM(2,1)
      ADJ(2,2)=SUM(1,1)
      DO 70037 JJ=1,2
      DO 70037 KK=1,2
70037 INVSUM(JJ,KK)=ADJ(JJ,KK)/DET
      DO 70038 JJ=1,4
      DO 70039 KK=1,2
      S=0.
      DO 70040 LL=1,2
70040 S=S+PPHT(JJ,LL)*INVSUM(LL,KK)
70039 KGAIN(JJ,KK)=S
70038 CONTINUE
      Z(1)=FLOAT(IBEAR(J1))
      Z(2)=FLOAT(IRNGE(J1))
```

```
      DO 70041 JJ=1,2                                                   COR02090
      S=0.                                                              COR02100
      DO 70042 KK=1,4                                                   COR02110
70042 S=S+HH(JJ,KK)*X(KK)                                               COR02120
70041 HHX(JJ)=S                                                         COR02130
      DO 70043 JJ=1,2                                                   COR02140
70043 HHX(JJ)=Z(JJ)-HHX(JJ)                                             COR02150
      DO 70044 JJ=1,4                                                   COR02160
      S=0.                                                              COR02170
      DO 70045 KK=1,2                                                   COR02180
70045 S=S+KGAIN(JJ,KK)*HHX(KK)                                          COR02190
70044 KZHX(JJ)=S                                                        COR02200
      DO 70046 JJ=1,4                                                   COR02210
70046 X(JJ)=X(JJ)+KZHX(JJ)                                              COR02220
      DO 70047 JJ=1,2                                                   COR02230
      DO 70047 KK=1,4                                                   COR02240
70047 PPHTT(JJ,KK)=PPHT(KK,JJ)                                          COR02250
      DO 70048 JJ=1,4                                                   COR02260
      DO 70049 KK=1,4                                                   COR02270
      S=0.                                                              COR02280
      DO 70050 LL=1,2                                                   COR02290
70050 S=S+KGAIN(JJ,LL)*PPHTT(LL,KK)                                     COR02300
70049 KKPHTT(JJ,KK)=S                                                   COR02310
70048 CONTINUE                                                          COR02320
```

```
      DO 70051 JJ=1,4                                                   COR02330
      DO 70051 KK=1,4                                                   COR02340
70051 I_RMT$PMATRIX(JJ,KK)=I_RMT$PMATRIX(JJ,KK)-KKPHTT(JJ,KK)           COR02350
70027 J=J+1                                                             COR02360
      GOTO 70015                                                        COR02370
70017 THETA=FATAN2(X(2),X(1))                                           COR02380
      THETA=INT(THETA*(180./3.141592654)+.5)                            COR02390
      RNG=SQRT(X(1)*X(1)+X(2)*X(2))                                     COR02400
      F_RMT$TMALAT=F_POS1$LAT                                           COR02410
      F_RMT$TMALON=F_POS1$LON                                           COR02420
      COSL=F_POS1$COSLAT                                                COR02430
      CALL RRB2LL(F_RMT$TMALAT,F_RMT$TMALON,RNG,THETA,0.,COSL)          COR02440
      KPOINT_RMT=IRMTF(K1)                                              COR02450
      IBB(KPOINT_RMT+8)=IOR(IAND(IBB(KPOINT_RMT+8),NOT(ISHFT(65535,0))),COR02460
     *ISHFT(IAND(INT(.5+(F_RMT$TMALAT--3.2)/.0001),65535),0))           COR02470
      IBB(KPOINT_RMT+8)=IOR(IAND(IBB(KPOINT_RMT+8),NOT(ISHFT(65535,16)))COR02480
     *,ISHFT(IAND(INT(.5+(F_RMT$TMALON--3.2)/.0001),65535),16))         COR02490
      CSE=FATAN2(X(4),X(3))                                             COR02500
      CSE=INT(CSE*(180./3.141592654)+.5)                                COR02510
      SPD=SQRT(X(3)*X(3)+X(4)*X(4))                                     COR02520
      IBB(KPOINT_RMT+5)=IOR(IAND(IBB(KPOINT_RMT+5),NOT(ISHFT(511,0))),ISCOR02530
     *HFT(IAND((CSE),511),0))                                           COR02540
      IBB(KPOINT_RMT+4)=IOR(IAND(IBB(KPOINT_RMT+4),NOT(ISHFT(4095,16))),COR02550
     *ISHFT(IAND((SPD),4095),16))                                       COR02560
```

```
      CONST1=I_RMT$PMATRIX(1,1)-I_RMT$PMATRIX(2,2)
      CCNST2=I_RMT$PMATRIX(1,2)*I_RMT$PMATRIX(1,2)
      CONST=SQRT(CONST1*CONST1/4.+CONST2)
      I_RMT$SIGMASQR=(I_RMT$PMATRIX(1,1)+I_RMT$PMATRIX(2,2))/2.+CONST
      I_RMT$2SIGMA=SQRT(I_RMT$SIGMASQR)*2./2025.
      IF(I_RMT$2SIGMA.LE.500)THEN
         I_RMT$TMAQUALITY=2
      ELSE IF(I_RMT$2SIGMA.GT.500.AND.I_RMT$2SIGMA.LE.1000)THEN
         I_RMT$TMAQUALITY=1
      ELSE
         I_RMT$TMAQUALITY=0
      END IF
      IBB(KPOINT_RMT+9)=IOR(IAND(IBB(KPOINT_RMT+9),NOT(ISHFT(3,4))),ISHF
     *T(IAND((I_RMT$TMAQUALITY),3),4))
70016 K=J
      GOTO 70009
70010 IVIEW=IVIEW+1
      GOTO 70003
70099 RETURN
      END
```

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